

# Efficiency and daily work effort in sugar cane cutters

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**ABSTRACT** Productivity (metric tons (tonnes)/day), efficiency (kg cane cut/litre  $\dot{V}O_2$ ), and effort (percent  $\dot{V}O_{2\text{ max}}$  sustained during an 8-hour workday) have been measured in 54 Colombian sugar cane cutters. In workers who sustained less than 40%  $\dot{V}O_{2\text{ max}}$  during the workday, the effort expended was related to productivity ( $r = 0.71$ ) but efficiency and productivity were not significantly correlated. In 16 workers sustaining a greater than 40%  $\dot{V}O_{2\text{ max}}$  during the workday, productivity and effort were not related and efficiency was significantly reduced. Subjects using less than 40%  $\dot{V}O_{2\text{ max}}$  were divided into good, average and poor producers and compared with the men with low efficiencies. In general, these inefficient men had the anthropometric and physical fitness characteristics of low productivity workers (smaller stature, weight and  $\dot{V}O_{2\text{ max}}$ ). However, the frequency of good, average, and poor cutters in the inefficient group did not differ from that of the men expending less than 40% of their maximum effort nor was their average productivity different. No obvious reasons for the differences in efficiency and effort of these men were found.

The developing nations rely largely on manual labour to accomplish daily work tasks rather than on the use of more expensive machines. For example, Morrison and Blake (1974) pointed out that, of the 500 million tonnes (t) of sugar cane produced annually in the world, over 75% is cut by hand. Sugar cane cutting is heavy work and, because the productivity can be measured relatively easily, these workers have been the subjects of several studies in recent years (Fenwick and Figenschou, 1972; Davies, 1973; Morrison and Blake, 1974; Spurr *et al.*, 1975, 1976).

A previous report from this laboratory (Spurr *et al.*, 1975) showed that Colombian sugar cane cutters worked at an average intensity of about 35% of their  $\dot{V}O_{2\text{ max}}$  during the 8-hour workday. This value is in apparent agreement with that found in the laboratory by Michael *et al.* (1961) for 8 hours of work, and lower than values proposed by Åstrand (1960). The subjects of Michael *et al.* (1961) were able to work for 8 hours provided that the effort did not exceed 35% of the  $\dot{V}O_{2\text{ max}}$ .

About 30% of the cutters in Colombia exerted an

effort in excess of 40% of their  $\dot{V}O_{2\text{ max}}$  during the 8-hour workday. The data have been examined to determine whether those workers using a greater percentage of  $\dot{V}O_{2\text{ max}}$  were in any way different from their co-workers.

## Methods

In the State of Valle del Cauca, Colombia, where these studies were performed, sugar cane is harvested throughout the year. Consequently, the problem of seasonal activity was not encountered. The men engaged in the cutting of sugar cane are paid by the metric tonne which is cut, trimmed and stacked. Thus, accurate accounts are kept of each man's productivity. Cutters do not help to load the cane, therefore their daily activity constitutes almost continuous cutting for the 8-hour workday with only brief breaks for water and for sharpening their machetes (Spurr *et al.*, 1975). Approximately 1 hour is taken for the noon meal which is eaten in the field. All measurements are for men cutting green, unburned sugar cane.

Details of subject selection, type of work, and the laboratory studies performed have been presented previously (Spurr *et al.*, 1975). Briefly, the subjects

studied were male employees of a large sugar cane growing and processing firm. They were selected from company records on the basis of established productivity and low absenteeism, the latter to rule out chronic disease as a factor affecting productivity.

The energy cost of cutting sugar cane was determined in the field using a Kofranyi-Michaelis meter as described by Consolazio (1971) and shown in Fig. 1. Heart rates were measured by means of a Parks Telemetry System.  $\dot{V}O_2$  and heart rates ( $f_H$ ) were determined in the morning and again in the afternoon, at rest and between 5-10 minutes and 20-25 minutes after restarting work. During each 5-minute period of measurement, the cut cane was carefully collected and weighed. This enabled the following calculations to be made:

$$(1) \text{ Efficiency} = \frac{\text{Work done}}{\text{Energy cost of work}} = \frac{\text{kg cane cut}}{\dot{V}O_2 (l)}$$

The reciprocal of efficiency times the kg cut each day (productivity) divided by the 480 minutes in an 8-hour workday gave an estimate of the average  $\dot{V}O_2$  sustained, and this divided by the  $\dot{V}O_{2 \max}$  gave the percentage which would have to be sustained during an 8-hour workday. Thus:

$$(2) \text{ Sustained } \% \dot{V}O_{2 \max} = \frac{\text{Productivity}}{\text{Efficiency} \times 480 \times \dot{V}O_{2 \max} (l/\text{min})} \times 100$$

This equation enables the daily effort to be estimated.

Later in the same week the cutters were transported to the exercise laboratory for anthropometric measurements and determination of the  $\dot{V}O_{2 \max}$ . Scapular and triceps skinfolds were measured with Lange skinfold calipers and body fat calculated (Pascale *et al.*, 1956; Brozek *et al.*, 1963). Body weight was measured to  $\pm 25$  g with a Horns beam scale, and height was determined to the nearest millimetre.



Fig. 1 A cane cutter using his machete while wearing a Kofranyi-Michaelis meter.

Before the  $\dot{V}O_{2 \max}$  test, a standard 12-lead electrocardiogram was obtained with the subject supine. During the  $\dot{V}O_{2 \max}$  tests heart rates were monitored using a bipolar, precordial lead and a Grass polygraph. No significant electrocardiographic abnormalities were noted in any of the subjects, either before or during the tests.

A modified Balke and Ware (1959) procedure was employed for the  $\dot{V}O_{2 \max}$  determination. Heart rates and  $\dot{V}O_2$  were measured by standard techniques previously described. Maximum values were established for each subject undergoing  $\dot{V}O_{2 \max}$  testing by the occurrence of the plateau (that is, an increase of  $\leq 150$  ml/min in  $\dot{V}O_2$ ) or decrease in  $\dot{V}O_2$  when reaching supramaximal work loads (Taylor *et al.*, 1958), an abrupt increase in  $\dot{V}E$  and decrease in  $\dot{V}E/\dot{V}O_2$  upon reaching  $\dot{V}O_{2 \max}$  and/or the inability of the subject to keep up with the treadmill in spite of strong encouragement from the observers. These criteria were applied rigidly to all 60 cutters tested and resulted in the rejection of five of the cutters. One additional subject was not included because of failure to obtain acceptable productivity data.

Statistical comparisons were made on the basis of paired or unpaired Student's *t* or *F* ratio tests (one-way analysis of variance) as required. The various statistical tests were applied as described by Snedecor (1956), and the null hypothesis rejected at the 5% level. Data are presented as means and standard deviations unless indicated otherwise.

## Results

Figure 2 is a graphic presentation of productivity and the estimated percentage  $\dot{V}O_{2 \max}$  which workers have to sustain to achieve their daily productivity. An arbitrary level of 40%  $\dot{V}O_{2 \max}$  (Michael *et al.*, 1961; Åstrand and Rodahl, 1970) was chosen as a dividing point for purposes of statistical analysis. When the sustained effort is less than 40% of the  $\dot{V}O_{2 \max}$ , the correlation ( $r = 0.71$ ) between productivity and sustained percentage  $\dot{V}O_{2 \max}$  is statistically significant and simply indicates that productivity is related to effort. However, above 40% the correlation coefficient is not statistically significant; the slope of the regression line is not significantly different from zero but is significantly different from the slope of the regression line for those who exerted less than 40% effort during the workday ( $P < 0.05$ ). Consequently, there is statistical justification for treating the two groups separately.

Sugar cane cutters have been described as good, average or poor on the basis of their productivity (Davies, 1973; Spurr *et al.*, 1975). We have classified our subjects as shown in Table 1, which also presents the frequency distribution and average pro-

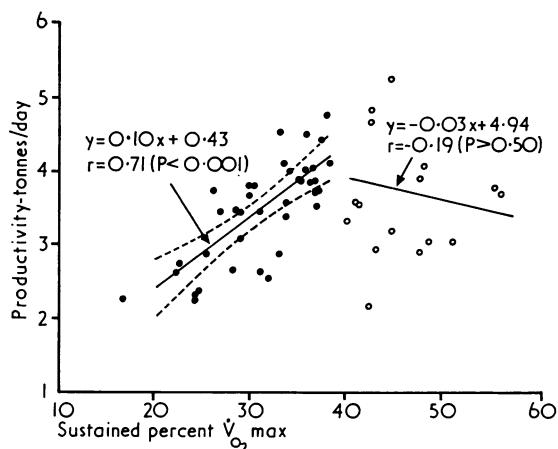


Fig. 2 Regression of productivity on the percent  $\dot{V}O_2$  max sustained during the 8-hour workday in 38 sugar cane cutters who exerted less than 40% and 16 who expended greater than 40% effort.

ductivity of the subjects in each of the productivity groups, above and below a sustained 40% of  $\dot{V}O_2$  max. A  $\chi^2$  analysis demonstrated that there was no difference in the frequency of men in each of the three productivity groups (Table 1), nor were the average productivities different in the two effort groups.

Because of the different relationships between effort and productivity in the subjects above and below a sustained effort of 40%  $\dot{V}O_2$  max (Fig. 2), separate groups were defined. Those below 40% were subdivided into three productivity groups (Table 1), while those above 40% were combined into one group called Group 4. A one-way analysis of variance of a number of physiological variables was then applied to the four groups of subjects. These results are presented in Table 2. In general, the results obtained in Groups 1, 2, and 3 are similar to those presented earlier for these subjects (Spurr *et al.*, 1976). For example, the analysis of variance of  $\dot{V}O_2$  max for Groups 1, 2, and 3 gave an F ratio of 8.95 ( $P = 0.001$ ). With the exception of the average age, subjects in Group 4 had mean values for height, weight, percentage body fat and lean body mass which were similar to those found in Group 3 or fell between the averages of Groups 2 and 3. The average productivity of Group 4 was similar to that of Groups 1, 2, and 3 (Table 1). However, the mean percentage of  $\dot{V}O_2$  max which was sustained for the 8-hour workday, was  $46.5 \pm 5.4\%$  which was significantly higher than that of any of the other three groups (Table 2). This amounts to an 8-hour sustained work rate of  $23.45 \pm 3.77$  kJ/min (1 kcal  $\approx 4.2$  kJ), or, as the average body weight in this group was 55.8 kg, to 27.21 kJ/min/65 kg (Durnin and Passmore, 1967).

Table 1 Productivity (metric tonnes/day) of good, average and poor sugar cane cutters exerting less than and greater than 40% of  $\dot{V}O_2$  max during the 8-hour workday

Productivity group	Effort					
	<40% $\dot{V}O_2$ max			>40% $\dot{V}O_2$ max		
	n*	Mean	SD	n*	Mean	SD
1 (>4 t/day)	6	4.36	0.27	4	4.66	0.50
2 (3.4 t/day)	21	3.65	0.24	7	3.55	0.24
3 (<3 t/day)	11	2.54	0.23	5	2.78	0.36

\* $\chi^2 = 0.82$  ( $P > 0.60$ ).

Table 2 Means and standard deviations of anthropometric and physiological variables of sugar cane cutters divided into good, average and poor producers (groups 1 to 3) and a group which exerted in excess of 40%  $\dot{V}O_2$  max during the workday (group 4)

Variables	Subject groups				F ratio (probability)
	1 (n = 6)	2 (n = 21)	3 (n = 11)	4 (n = 16)	
Age (yr)	27.7 $\pm$ 2.0	29.7 $\pm$ 7.2	26.4 $\pm$ 6.2	31.5 $\pm$ 7.4	1.41 (0.025)
Height (cm)	170.1 $\pm$ 6.7	163.5 $\pm$ 4.6	159.4 $\pm$ 6.1	162.2 $\pm$ 6.6	4.58 (0.006)
Weight (kg)	62.8 $\pm$ 5.9	58.7 $\pm$ 4.4	55.7 $\pm$ 4.4	55.8 $\pm$ 6.0	3.61 (0.02)
Percent body fat	9.7 $\pm$ 0.7	9.9 $\pm$ 1.1	10.8 $\pm$ 1.3	10.3 $\pm$ 1.6	1.52 (0.22)
Fat-free mass (kg)	56.7 $\pm$ 5.4	52.9 $\pm$ 3.8	49.7 $\pm$ 4.1	50.0 $\pm$ 4.8	4.84 (0.005)
$\dot{V}O_2$ max (l/min)	3.13 $\pm$ 0.37	2.73 $\pm$ 0.30	2.48 $\pm$ 0.27	2.42 $\pm$ 0.28	10.02 (<0.001)
$\dot{V}O_2$ max (ml/kg $\cdot$ min <sup>-1</sup> )	50.4 $\pm$ 4.7	46.6 $\pm$ 4.2	44.7 $\pm$ 5.6	42.5 $\pm$ 3.2	5.60 (0.002)
Maximum heart rate (beats/min)	176 $\pm$ 6	181 $\pm$ 10	188 $\pm$ 12	183 $\pm$ 11	1.88 (0.20)
Estimated sustained % $\dot{V}O_2$ max	34.6 $\pm$ 2.3	32.2 $\pm$ 3.5	26.2 $\pm$ 5.1	46.5 $\pm$ 5.4	53.73 (<0.001)
Efficiency (kg cane/l $\dot{V}O_2$ )	8.8 $\pm$ 1.2	8.9 $\pm$ 1.2	8.6 $\pm$ 1.3	7.1 $\pm$ 1.8	5.91 (0.002)

Previously, efficiency of cutting cane was shown to be higher in the afternoon than in the morning and did not differ in the three productivity groups (Spurr *et al.*, 1975). To obtain an estimated daily value of efficiency for each man, the morning and afternoon differences were ignored and the average taken. There was no difference in Groups 1, 2, or 3, but Table 2 shows that Group 4 had a significantly lower average efficiency of 7.1 kg/litre  $\dot{V}O_2$  ( $F = 5.91$ ;  $P < 0.002$ ).

Table 2 also presents the  $\dot{V}O_{2 \max}$  (litres/min), aerobic capacity ( $\text{ml/kg} \cdot \text{min}^{-1}$ ) and maximum heart rates of the four groups. An analysis of variance showed a statistically significant F ratio for  $\dot{V}O_{2 \max}$  ( $P < 0.001$ ) and aerobic capacity ( $P < 0.002$ ). Unpaired Student's *t* test comparisons showed that, in both instances, the values for Group 4 were significantly less than those for Groups 1 and 2, but were not statistically different from those for Group 3. Maximum heart rate ( $f_{H \max}$ ) was not significantly different for the four groups, although poorer producers tended to have higher  $f_{H \max}$  than the better producers. It is unlikely that the apparently low values for  $f_{H \max}$  (Table 2) were the result of not achieving maximum values, as all subjects satisfied the criteria established for maximum. In addition, when sugar cane cutters were compared with other groups of labourers, it was found that the former had significantly lower maximum heart rates than had either general farm labourers in Colombia or two groups of labourers in the United States, while the cane cutters achieved significantly greater total work loads on the treadmill (Maksud *et al.*, 1976).

Using the  $f_H$  and  $\dot{V}O_2$  values measured during work in the field, a slope and intercept of the regression of  $f_H$  on  $\dot{V}O_2$  was calculated for each subject in the morning and afternoon, and an  $f_H$  at  $\dot{V}O_2 = 1.5$  litres/min ( $f_{H1.5}$ ) obtained from the resulting equations (Spurr *et al.*, 1975). As statistical analyses of the morning or afternoon results, or the average of the two sets, led to the same conclusions, only the latter results are presented. The values for  $f_{H1.5}$  were  $124 \pm 9$ ,  $135 \pm 16$ ,  $144 \pm 15$  and  $140 \pm 10$  beats/min for Groups 1, 2, 3, and 4, respectively. The one-way analysis of variance gave an F ratio of 2.95 ( $P < 0.05$ ). The  $f_{H1.5}$  for Group 4 was significantly higher than that for Group 1 but not significantly different from those for Groups 2 and 3. Resting heart rates in the field were not significantly different among the four groups in the morning ( $F = 0.38$ ;  $P > 0.75$ ) or afternoon ( $F = 0.27$ ;  $P > 0.80$ ).

## Discussion

In discussing the percentage of  $\dot{V}O_{2 \max}$  which can be sustained for 8 hours' work, Åstrand and Rodahl

(1970) state that a 50% load is too high for a steady state if the physical activity is continuous for a whole working day. Michael *et al.* (1961) showed that only work loads below 35% of maximum could be sustained without undue fatigue for 8 hours by three young men working in the laboratory. The estimates of the percentage  $\dot{V}O_{2 \max}$  used by Colombian sugar cane cutters during an 8-hour workday were made on the basis of several short periods of measurement in the field which were projected to 8 hours (Spurr *et al.*, 1975). The 16 men who exhibited no relationship between productivity and sustained percentage  $\dot{V}O_{2 \max}$  above 40%  $\dot{V}O_{2 \max}$  were found to have an average productivity very close to the average of Groups 1, 2, and 3 or to Group 2 alone (Table 2). The mean height, percentage body fat and  $f_{H1.5}$  of Group 4 were between those found for the average and low producers, and the weight and lean body mass were almost equal to those found for the poorer producers (Table 2). The latter was also true for the total  $\dot{V}O_{2 \max}$  (litre/min) after normalisation for body weight. It would seem therefore that, in terms of anthropometry and physical fitness, it would be more appropriate to classify the men in Group 4 with the poorer producers. However, the relatively low efficiency and therefore high percentage of  $\dot{V}O_{2 \max}$  expended during the 8-hour workday clearly set Group 4 apart from the others. It is interesting to note that Morrison and Blake (1974) used the same measure of efficiency and that their Rhodesian cutters, who were also harvesting green cane, had an average efficiency of 6.3 kg cane/litre  $\dot{V}O_2$ , which is comparable to the inefficient Colombian cutters in Group 4.

The causes of the inefficiency of Group 4 are unknown. The absence of differences in the resting heart rates obtained while the subjects were wearing the equipment used for the field measurements indicates that the subjects in Group 4 were not under particular emotional stress arising from the tests. These men were as experienced in cutting cane as were those in the other three groups, and their machetes were similar (Spurr *et al.*, 1975). A number of studies have shown that the tools employed in a particular task may influence the efficiency with which the task is accomplished (Åstrand and Rodahl, 1970). We do not have a measure of the sharpness nor of the condition of the machetes employed, but assume that one of the first things a cutter learns is the care of his implement. All of the cutters were in a good nutritional state at the time of the study (Spurr *et al.*, 1975). That the men in Group 4 had a lower mean  $\dot{V}O_{2 \max}$  and aerobic capacity than the others indicates that they were in poorer physical condition (Åstrand and Rodahl, 1970), and this can be deduced also from the calculated  $f_{H1.5}$  during work.

Nevertheless, these men were able to maintain a work rate of 26.8 kJ/min per 65 kg which amounted to about 47% of their  $\dot{V}O_{2\text{ max}}$  during the 8-hour workday. Both of these figures are higher than the values of about 20.9 kJ/min per 65 kg (Passmore and Durnin, 1955), and 35%  $\dot{V}O_{2\text{ max}}$  (Michael *et al.*, 1961) which are the upper limits that men can expend during a regular workday. This raises the question of motivation, which is known to play an important role in man's ability to perform physical work and in his capacity to endure conditions of heavy physical labour (Åstrand and Rodahl, 1970). The present investigation was not designed to study motivation. However, the results show that about 30% of the sugar cane cutters in this study had a normal distribution of productivity (Table 1) in spite of low efficiency and physical fitness, and anthropometric measurements which would place them in the category of poor producers. The motivating factors involved in their markedly increased effort to maintain this productivity would make an interesting psychological study. In addition, the long-term consequences of such efforts should be investigated.

This work was supported in part by Contract AID/CSD 2943 with the Office of Nutrition, Agency for International Development, and was also supported by the Medical Research Service of the Veterans Administration.

The authors wish to express their appreciation to Central Castilla, Ltda., Colombia, for the very generous co-operation extended by them during the conduct of this study. The helpful assistance of Dr Guillermo Ayalde and the willing participation of the cutters is especially acknowledged.

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